Guidelines for Cage Culture of Atlantic Halibut in Canadian Maritime Waters

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ABSTRACT

Stuart, E.J., Martin-Robichaud, D.J., Power, J.E., Benfey, T.J., Wolf, G. and Blanchard, B. 2010. Guidelines for cage culture of Atlantic halibut in Canadian Maritime waters. Can. Tech. Rep. Fish. Aquat. Sci. 2860: v + 24 p.

High market value and good growth rate at low water temperatures makes Atlantic halibut, *Hippoglossus hippoglossus*, an ideal species for coldwater marine aquaculture in Atlantic Canada. This manual outlines knowledge gained through a 3- year multi-partner research program to evaluate the potential for successful cage culture of halibut in the Bay of Fundy. The unique climatic and oceanographic conditions of this environment preclude simply copying methods developed in other countries for this purpose. Details are provided on site selection criteria and cage design, accessing and transporting juveniles, best husbandry practices (nutrition, feeding techniques, mortality dives, grading and harvesting, net cleaning and shading, and stocking densities) and economics and marketing. It is reasonable to expect that culture technologies will become more advanced with industry growth, and it is hoped that this manual will aid the expansion of this industry.

RÉSUMÉ

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La haute valeur marchande et un bon taux de croissance aux basses températures d'eau font le flétan Atlantique, *Hippoglossus hippoglossus*, une espèce idéale pour l'aquaculture marine en eau froide dans le Canada Atlantique. Ce manuel décrit les connaissances acquises durant un programme de recherche multipartenaire de 3-ans pour évaluer le potentiel de l'élevage en cages de flétan dans la Baie de Fundy. Les conditions climatiques et océanographiques uniques de cet environnement prévient de simplement copier les méthodes développées à cette fin dans les autres pays. On fournit des détails sur les critères de sélection de site et la conception de cage, sur l'accès et le transport des juvéniles, sur les meilleures pratiques d'élevage (la nutrition, techniques d'alimentation, la plongée pour les morts, le triage et la récolte, le nettoyage et l'ombrage des filets, et la densité d'occupation), et sur l'économie et la commercialisation. Il est raisonnable de s'attendre à ce que les technologies de culture deviennent plus avancées avec la croissance de l'industrie et on espère que ce manuel aidera avec l'expansion de cette industrie.

1 INTRODUCTION

Aquaculture currently accounts for approximately 50% of the world's food fish supply and the industry is forecasted to grow. An additional 40 million tonnes of aquatic food will be required to sustain the current demand by 2030 (FAO, 2006). In 2007 Canadian aquaculture contributed 1.14% of the total global production – producing 153,000 tonnes at a value of $750 million (DFO, 2007). Of this total Canadian production, 103,000 tonnes of product (at a value of $605 million) can be attributed to the production of salmon, mainly Atlantic salmon (*Salmo salar*) (DFO, 2007). In New Brunswick, salmon culture accounts for 95% of the total aquaculture production (NBDAA, 2005). The intense and, in some cases, excessive stocking of salmon can lead to disease outbreaks, unwanted environmental effects, and a supply surplus resulting in a reduced market price. In recent years alternative species considered for culture to help diversify the industry include Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and Atlantic halibut (*Hippoglossus hippoglossus*).

Atlantic halibut, *Hippoglossus hippoglossus*, has been identified as an ideal candidate for farming in temperate waters as they maintain good growth rates in relatively cold northern waters (0-14°C) and can reach a predicted market size for farmed stocks of 3-5 kg, approximately 2-3 years post-weaning (Bromage *et al.*, 2000). The market value of Atlantic halibut in Europe is three times that of Atlantic salmon, *Salmo salar*. In addition to the high price and market demand for halibut, the appropriateness of the species for culture is also supported by the noted decline in wild stocks over the past two decades. Recent stock assessment reports by the Department of Fisheries and Oceans in the Maritimes region show evidence of decreasing wild halibut numbers in both the St. Lawrence and Scotian Shelf & Southern Grand Banks stocks, with indications of decreases in total landings, coinciding with a decrease in the total allowable catch (DFO 2001, 2004). By culturing the fish it is hoped that, in offering a year round supply to buyers, fishing pressure on the wild stocks will be reduced, allowing the wild stock to recover. In addition to this, aquaculture has the advantage of making a fresh, healthy product available year-round, while fisheries can only supply markets during the fishing season, and even then fish can only be as fresh as processing and distribution allow. Many salmon farmers with leases for sea cage sites for salmon farming are interested in diversifying their production. This is partially due to the high price fluctuations in salmon markets resulting from large volumes of cultured salmon from Norway and Chile, in addition to serious production problems related to disease outbreaks of infectious salmon anaemia (ISA). Recently Atlantic halibut have been grown in modified salmon cages, relieving the need for high initial infrastructure costs to start production, however, this cage technology may not be ideal for flatfish farming and farmers are encouraged to investigate newer technology used in other countries specifically designed for halibut farming.

Developing culture technology for Atlantic halibut started in Norway, Iceland and Canada in the early 1990s. Progress was slow as initial problems with the early rearing stages were overcome. Now stable production of juvenile halibut is a reality in Iceland, Europe and Canada. The current focus is to increase grow-out operations for juvenile to market fish. At present, both land-based and cage culture are being carried out in Europe. There is a great deal of debate on which type of halibut culture is more economically viable. Some feel that in order for halibut aquaculture to succeed, the best chance of economic success is in cage-culture. The capital investment cost of cage culture is lower than land-based tank culture because of the high initial set-up costs of tank

culture, and the cost of pumping water through a land-based facility. There is also the opportunity to modify existing salmon cages to be used for halibut grow-out, which makes cage-culture of halibut even more appealing in terms of reducing initial costs. However, land-based halibut growers argue that although the initial setup costs of land-based tank culture is significant, the ability to maintain optimal temperatures, and other husbandry conditions that generate faster growth, the ease of installing shelving in tanks to increase rearing density, increased biosecurity, and reduced environmental concerns outweigh the initial costs in the long run.

With the industry in its infancy in Atlantic Canada, companies are more willing to grow halibut in sea-cages because the opportunity exists to use modified salmon cages although this cage technology is not optimal for flatfish. Once the industry is more established, companies may attempt to build land-based facilities, particularly with the prospect of producing their own juveniles in mind.

Canadian researchers have also developed a few strategic biotechnology tools to give Canadian halibut producers an internationally competitive edge. Female Atlantic halibut grow faster and reach a larger size than males. Techniques and broodstock are now available in Atlantic Canada to produce all-female stocks for production (Tvedt *et al.*, 2006; Hendry *et al.*, 2003). Most countries are beginning to use F1 broodstock. Canadian researchers have also recently published a genetic map of the halibut genome and identified various molecular markers correlated to desirable traits such as growth (Reid *et al.*, 2007). Such advancements will be an asset to the industry once full scale production has been realized.

Although the research stage of halibut culture has been established, the commercial development stage is still struggling in Atlantic Canada. At this time there is a single hatchery, Scotian Halibut Ltd., (PO Box 119, Clark's Harbour, Nova Scotia B0W 1P0). This hatchery has the capability of producing 600,000 halibut juveniles for commercial production and is currently selling juveniles globally for grow-out. Canadian aquaculture companies have recently faced serious financial setbacks and consolidation due to issues encountered with salmon farming. Although they are eager and willing to engage in halibut culture, the initial cost of purchasing juvenile fish, before equity from marketing products is available, stifles the development of this industry. Finance agencies also want verified production data and business models for halibut culture under local conditions. The Bay of Fundy has extreme conditions that require specialized technology. Existing technologies for halibut cage production in Norway may not be suitable for the Canadian Maritime environment. The current project, for which this manual is being written, funded by numerous agencies (AquaNet, NBIF, CCFI, DFO-ACRDP, NBDAA, ACOA, and BNB) was intended to gain information on sea-cage culture, evaluate different protocols and recommend those that seem most suitable. Over time, with trial and error, improvements will continue to foster a viable halibut aquaculture industry.

For this project, Atlantic halibut are currently being grown by Canadian Halibut Inc. in modified salmon cages in Lime Kiln Bay near St. George, New Brunswick (Figure 1). This particular area is ideal for halibut cage-culture, as it is sheltered from wind and strong currents, an asset for growing halibut. The purpose of this manual is to discuss some of the standard operating procedures (SOPs) gained from literature, or expert opinions and developed and tried at Canadian

Halibut Inc. over the entire grow-out period, starting with the transport of halibut juveniles to the cage site, through the grow-out season and ending with the harvest of market size halibut.

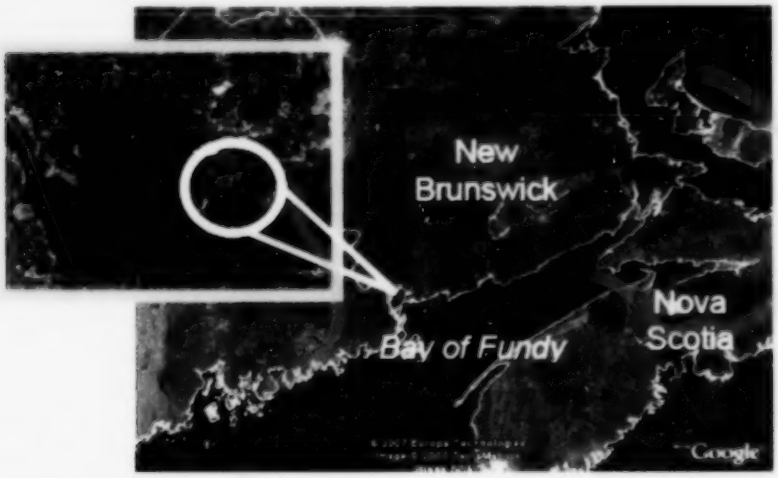

Figure 1. Location of halibut rearing site in Lime Kiln Bay, New Brunswick.

2 CAGE SITE PREPARATION

The grow-out of Atlantic halibut juveniles in sea-cages in Atlantic Canada is still in developmental stages. Many of the SOPs are being worked out by each farmer, and improvements are continuously being implemented. The next section will discuss farm protocols and cage designs developed to date. The techniques and protocols referred to in this manual have been derived from scientific literature as well as on-site experience at the grow-out operation of Canadian Halibut Inc. and recommendations derived from the authors' experiences and discussion with other industry contacts.

2.1 SITE SELECTION

2.1.1 Environmental Parameters and Considerations

In the wild, Atlantic halibut occupy the deeper waters of the north Atlantic and parts of the Arctic Ocean, seldom entering waters of less than 60 metres. They may also be encountered in the North Sea and the western part of the Baltic Sea. As they are normally a benthic organism, Atlantic halibut have a low tolerance of high currents and turbulence (Brown, 2002) and can experience a loss of appetite or mortality following exposure to excessive current speeds and swells, so sheltered areas are preferred (Bromage *et al.* 2000). The farmer should also consider the weather conditions the site will be exposed to year round. In the Bay of Fundy, experiences have shown that some areas are more prone to super chill than others due to tides, spring runoff and low temperatures. Therefore, the farmer should ensure the site is located in an open area where extreme cold water and ice will not be an issue during winter months. Although Atlantic halibut may be able to tolerate less oxygen than salmon, as they move slowly and normally spend time lying on the bottom of the cage, careful monitoring of oxygen levels at sites should be conducted

and sites selected accordingly. Jonassen *et al.*, 2000 found oxygen consumption of halibut was higher during darkness indicating that light may actually suppress activity. Because of their tendency to stay deep in the water column, halibut have low tolerance for sunlight and it should be ensured that the site is deep enough for them to avoid UV light as much as possible (Bricknell *et al.*, 1996). This can also be taken care of by the addition of shade covers to cages which will be discussed in a separate section. Growth and feed conversion of halibut juveniles is also better at salinities 28 to 32 ppt (Imsland *et al.*, 2008). The optimum temperature for Atlantic halibut juveniles decreases as fish grow. The optimum temperature is 14, 11 and 10°C for 10-60 g, 100-500 g and 3-6 kg fish, respectively, although larger juveniles will continue to feed down to about 4°C (Björnsson and Tryggvadóttir, 1996; Jonassen *et al.*, 1999). In choosing a site for halibut culture it is important to take these factors into account, as optimal conditions are important in the efficiency and performance of cultured fish.

For the current study, the cage site was situated in a sheltered area of the Bay of Fundy (figure 1), although high winds and waves did prevail in times of poor weather conditions sometimes creating rough wave conditions. Unique to the Bay of Fundy, extreme tidal changes ($\geq$ 5 m) played a role in the stability of the cage nets. Near surface water temperatures fluctuated annually between close to 0°C, in January and February, and as high as 14°C in the upper water column in late summer months. Light intensities were measured during late summer months to determine the highest light intensities experienced at the surface of the cages; these did not exceed 500 lux. Oxygen and nitrogen levels were measured within cages throughout the year and remained around 90% saturation.

2.1.2 Access

The farmer should also consider the accessibility of the site. To ensure proper husbandry and attendance to the needs of the fish, the sight must be accessible daily, year round. Also, it should only be in the case of adverse weather conditions that staff are unable to reach the site although safety is the primary consideration. Ice cover will result in severe mortalities so sites susceptible to ice cover should not be considered.

The farmer should also consider the access to juveniles with respect to the site's location. Further discussion in the "Transport" section will address transport issue, but in placing the site, the farmer should be aware of the distance juveniles will have to be transported from the hatchery to reach the site and the appropriate transport methods available.

2.1.3 New Brunswick Site Regulations

Once a site has been chosen, in order to farm halibut in New Brunswick, it is necessary to first acquire a site license from the New Brunswick Department of Agriculture and Aquaculture (NBDAA). Contact NBDAA to determine the requirements for non-salmonid species and whether new marine species considered for culture are required to be grown on pre-established licensed sites as policies are currently in development. Refer to the NBDAA Marine Aquaculture Site Allocation Policy (http://www.gnb.ca/0168/EastCoastSiteAllocationPolicy.pdf) and the site application form (http://www.gnb.ca/0177/01770007a-e.pdf). A baseline environmental

assessment is required by the NBDAA before a halibut farm is established and results of this assessment are to be made available upon applying for the site license.

2.1.3.1 Environmental assessments

Little is known about the environmental impacts of halibut cage culture and how it compares to salmon farming. It is assumed that because halibut feed off the bottom as well as within the water column, some of the wastes caused by excess feeding would be eaten by the fish, thus reducing the waste. It is proposed that with proper feeding, halibut farming could have less of an impact on the environment underneath the cage site because of their bottom feeding tendencies. The intention of a baseline assessment is to help monitor and compare the impact over time and create a proactive approach to environmental monitoring. Annual environmental assessments of sites with active licenses in New Brunswick are required by the New Brunswick Department of Environment and are to be completed at the expense of the farmer.

2.2 JUVENILE AVAILABILITY

If a Canadian hatchery plans to export juveniles internationally for grow-out then they must research the import requirements of the country they will be sending their product to. Health certification for Canadian aquatic animal exports is based on importing country requirements. Therefore, the CFIA needs information from industry on which markets are being targeted for Canadian exports so certification requirements can be assessed well in advance of planned exports.

Importing live fish internationally is currently regulated through DFO, but CFIA will be responsible for the requirements once the regulations of the National Aquatic Animal Health program (NAAHP) are in place -starting spring 2010. As part of the proposed regulatory changes, aquatic animal health permits will be required to import live aquatic animals into Canada. Import permits for aquatic animals will require a health certification from the country of origin that the animals to be exported to Canada meet its aquatic animal health requirements. http://www.inspection.gc.ca/english/anima/aqua/aquae.shtml

2.2.1 Hatchery accessibility

In order to be successful, a halibut cage-culture site must have access to a hatchery or nursery facility with the capabilities of producing juveniles on a commercial scale. Not only must this production be streamlined for commercial purposes, but the hatchery must be located within reasonable travelling distance from the farm although small juvenile halibut (5-20g) are routinely shipped overseas for grow-out in nursery farms. Further remarks on juvenile transport will be made in the Transport section to follow.

2.2.2 Health Check

Juveniles for purchase for commercial grow-out should be of optimal health. For this reason, in choosing a juvenile source, the farmer should inquire as to the fish's health records, prior to purchase and transport. It may be useful to have an independent assessment of the fish done, by

outside fish health services, prior to purchase. This practice would be helpful in ensuring that the fish being purchased are in optimal condition, or if there are any external morphological problems that could impact the performance of the fish such as incomplete eye migration and missing eyes.

2.2.3 Size for Stocking

There is some controversy surrounding the best size for the transfer of juveniles to sea-cages. Practices in some European countries have seen fish transferred from a hatchery at 100 g, to a grower's land-based nursery facility, until they are at approximately 500 g, at which time they are transferred to sea-cages. In some other species, such as Atlantic cod (*Gadus morhua*), juveniles are being transferred to sea-cages at sizes as small as 10 g (Frank Powell, Cooke Aquaculture Inc., New Brunswick, *pers. comm.*). Halibut, as a flatfish species, are likely more sensitive to open water conditions than round fish species being cultured. In the wild, they tend to occupy shallow nursery grounds until they are 3 to 4 years of age, because of the protection and optimal temperatures offered. It is proposed that farmers would benefit from transferring fish at larger sizes since survival and performance may be better than that of halibut stocked at smaller sizes. A recent study found that although smaller fish (less than 300 g upon transfer) were noted to have higher growth rates over the first two years in cage culture, they showed poorer survival, and despite the higher growth rate, were still unable to 'catch-up' to those of larger sizes that reached harvest size (~ 4 kg) faster (Power, 2009). Size for transfer and the need to introduce fish into cages in the spring will be further discussed in Section 3.4.

2.2.4 Juvenile Cost

Farmers should discuss the price options for the purchase of juveniles with the hatchery. Because they must be kept for a longer period of time in the hatchery, larger juveniles may cost significantly more than smaller ones. The economics of a higher initial price but shorter growout period should be considered in the overall business plan. Also, if juveniles are not found to be in optimal condition and/or have a high degree of malpigmentation or incomplete metamorphosis as mentioned above then the price should be negotiated to reflect the value of the fish since these conditions will impact survival and performance.

2.3 CAGE DESIGN

2.3.1 Size and Structure

Sea cages used for halibut culture in New Brunswick are often modified 70-100 meter polar circles designed for salmon culture. The polar circle itself is not modified, however the nets and the method in which the nets are tied are different from those on salmon farms. Although accessible and convenient, modified polar circle cages are by no means ideal for halibut culture and anyone intending to rear halibut in cages would be advised to investigate newer technology developed in other countries.

2.3.1.1 Nets

Flatfish cages require a rigid bottom to prevent the net from sagging (Midling *et al.*, 1998). Some farms use a solid surface bottom for halibut cages. This setup may not be as practical in waters around the Bay of Fundy as wave action and currents could cause damage to a solid surface bottom. A more practical system would be to have the bottom of the fish net tied tightly at the bottom of the cage to create a flat surface for the halibut to lie on. The net is tied around the bottom surface to a 6 or 8 inch lead ring (the larger 8" ring is used in higher current areas) that surrounds the base of the cage. The size of mesh for the bottom surface of the net must be chosen carefully. Large mesh bases may result in excess feed waste as fish will not be given the opportunity to pick feed off the bottom (Brown, 2002), although the degree to which halibut feed off the surface of the net is under debate. However, if the mesh is too small, feed and feces will build up on the bottom of the cage. Mesh sizes of nets at the Lime Kiln site are ½ inch on the diagonal, which is quite small. A balance should be found between 'too large' where the feed pellets fall through before halibut can graze off bottom and 'too small', where waste will collect. As nets become fouled over time, divers may be required to bring up any excess feces and feed from the bottom on weekly dives to assess and collect fish mortalities. However, note that the dependence on divers for mortality dives and other activities can be very expensive so alternative strategies to minimize these costs are advised. Predator nets are even more critical for halibut rearing than in salmon cages because halibut spend a large portion of their time adjacent to, and lying on the netting, within easy reach of predators (Brown, 2002). The predator nets surround the fish net and are also tied to the ring. It is recommended that companies interested in developing cage culture of Atlantic halibut investigate new technological options as they develop in Canada and other countries since improvements are constantly being made.

2.3.2 Buoys and shelving

Tying the bottom of the cage out to the ring tightens the bottom and creates a surface for fish to lie on but it is important that the net surface supporting the fish should not be in contact with the outside net due to the potential for seal attacks. As fish grow and the biomass in the cage increases, cages may require the extra support from buoys. Another option for cages with high biomass is to add shelves since this uses more available space in the water column. Shelving allows farmers to stock higher numbers of fish in the same cage. Shelves may also help the fish behaviourally, in that they provide more space to avoid crowding, competition and associated aggressive behaviours. Shelves should start being used when densities reach 30-50 kg/m^2.

2.3.3 Depth

There is no set depth for halibut cages; depth ranges from 5 meters in Scotland to 30 meters in the Fjords of Norway. The depth of the cage is not dependent on density, unless shelving is being used, because the halibut usually occupy the bottom of the cage although mid-water swimming does occur especially during feeding. In Atlantic Canada, cages are approximately 7 meters deep. If cages become too shallow, UV light penetration may become a problem, so this must be taken into account when considering depth of cages. This will be further discussed in section 4.1.

3 TRANSPORT BEST PRACTICES

Transporting juvenile halibut from the nursery to sea-cages should become a routine procedure but at this point the only transport systems available were designed for salmon and are less than ideal for flatfish. As the industry expands technological improvements will occur. Until this point has been reached, innovation and common sense will prevail.

3.1 PERMITS

A transfer permit is required for transporting live fish between aquaculture sites. Approval by the importing province's federal-provincial Introductions and Transfers Committee (ITC) is required. Start this process well in advance. In order to receive a transfer permit, a representative sample of fish must be sent from the hatchery to an approved fish health laboratory for testing. Testing can take as long as 7 to 8 weeks. Contact DFO Regional Aquaculture Coordination Offices for details on Introductions and Transfer Licence Applications. The permit takes approximately 4-6 weeks to process. Drivers are required to have the permit with them during the transport. Upon arrival at the grow-out site, the DFO local Area Office must be notified of the transfer/introduction of fish into the sea cages.

3.2 FISH HEALTH

Along with the transfer permits, there are several pre-transport considerations to take into account, including fish vaccinations, taking fish off feed, and providing appropriate water parameters for a smooth transition from hatchery to seawater. Some hatcheries vaccinate juvenile halibut prior to transport; however, there are no commercial vaccines currently available that are specific for Atlantic halibut. Trials to date by Scotian Halibut Ltd. have shown that vaccines which are commonly used in salmonid aquaculture may actually make Atlantic halibut more susceptible to disease (Brian Blanchard, Scotian Halibut Ltd., Clark's Harbour, Nova Scotia B0W 1P0, *pers. comm.*). Halibut can be vaccinated with a common salmon vaccine which protects against *Aeromonas salmonicida* as well as *Vibrio anguillarum* and *Vibrio salmonicida*, however the effectiveness of this treatment is still in question. More research on vaccine trials is required to understand the effects of vaccines on Atlantic halibut specifically.

Fish should be checked for common parasites such as Costia (*Ichthyobodo*) - a protozoan parasite that can be introduced into salt water sites - from the hatchery. Costia can be easily seen on the gills using a dissection microscope. Immersing juveniles in a formalin bath will eliminate Costia. Professional fish health authorities can advise on treatments protocols. However if fish are reared in recirculation systems, the parasite may be difficult to eradicate. Scheduling the formalin bath for two weeks prior to transport may allow for the fish to recover from treatment stress before transport and another treatment may possibly be done in the transport truck prior to entry into cages to prevent introducing parasites into the cage environment. This is not common practice at Scotian Halibut Ltd., however, if problems with Costia arise in the future, this practice could become a common preventative measure. It is advised to get professional fish health advice prior to any chemical or vaccine treatments.

Halibut have a considerably longer gut passage time than salmonids and they should be removed from feed 48-72 h prior to transport to reduce metabolism and deterioration of transport water

during travel (Davenport *et al.*, 1990; Brown, 2002). Total gut clearance time is estimated by Davenport *et al.*, 1990 to be 120 h at 9.5-10.5°C. Gut emptying time is temperature dependant and slowed at cold temperatures, thus in these conditions they should be taken off feed for longer before transport.

3.3 TRANSFER SIZE

The optimal size of fish for transport to the sea cage is debatable. Economically, the optimal average fish size should be 200 grams or less. Scotian Halibut Ltd. conducted a cost analysis to determine the optimal size of fish at transfer. A maximum of 2500 kg of fish can be transported in a standard smolt truck, and each trip costs ~$3000 Canadian. Transporting smaller fish reduces the cost per fish. Redesigning the holding ability/capacity of the tanks should be considered to maximize cost efficiency of transport. Due to health and survivability concerns, some feel that fish can be safely transferred to sheltered sea cage sites only after they have reached 100 grams in weight (Bromage *et al.*, 2000). In Europe, halibut juveniles are generally sent to sea cages at a larger size of approximately 500 grams. It has been found that smaller fish, especially those less than 100 grams, do not survive or grow as efficiently in sea cages as larger fish (Brown, 2002; Power, 2009).

At the halibut farm in Lime Kiln Bay, New Brunswick several different sizes of fish were stocked in separate cages in order to examine growth of halibut juveniles ranging from 150 grams to 500 grams. Preliminary results indicate that although smaller fish at introduction to cage-culture grow at higher specific growth rates, larger fish, having the advantage of being larger upon entering the sea-cages, will still reach harvestable size before the smaller fish (Power, 2009). Also, larger fish had higher survivability over the course of a two year study in the sea-cages (Power, 2009).

3.4 DAY OF TRANSPORT

It is important to keep transport time under 24 hours. Consideration should be given to ensure arrival is timed for working and/or daylight hours at the site and consideration given to tidal factors. Barges, if required, should be scheduled to be available before the smolt trucks arrive. Snowy conditions can slow down transport and increase the chance of delays, and as stated before, introducing fish into cages in the winter is not advisable because of slow feeding response and recovery due to low and decreasing temperatures. Wind is also of major concern, especially if ferry transport is necessary. Other methods of transport should be considered such as boat or helicopter transport especially if it would reduce transport times.

Transporting juveniles can be extremely stressful for the fish; however, stress levels can be reduced by providing optimal conditions. The optimal water temperature in the transport tank is between 7 and 8°C, similar to what the fish were reared in at the hatchery. The water temperatures at the cage site should be no more than 1 to 2°C different than the water temperature in the hatchery. The hatchery should consider slowly adjusting the water temperatures at their facility to be within 1 to 2°C of the cage site water temperature several weeks prior to transport. Halibut can be transported in water temperatures ranging from 4 to 12°C. Avoid transporting fish when water temperatures at the cage site are less than 4°C or greater than 12°C. Optimal

seawater temperatures aid fish in recovery from transport, mechanical damage and handling stress. Winter transport of juveniles is particularly prone to problems and should be avoided. Ideally the transport should occur when seasonal water temperatures are increasing such as in mid to late spring to encourage a suitable feed response and aid overall fish recovery.

On the day of the transport, allow approximately 1-1.5 hours to fill each truck carrying five smolt tanks. Fish are hand dipped from the hatchery tanks into the smolt tanks, which are 5 m^2 with dimensions 4.2 m x 4.2 m x 1 m high. Halibut occupy the bottom of the tank during transport; therefore, density is a measure of bottom surface area. To ensure appropriate densities in transport tanks, fish should be kept so that there are no more than four layers of fish. It is possible to transport up to seven layers of fish, but it is more difficult to evenly distribute oxygen throughout all layers. Larger halibut can be kept at higher densities because of their thickness and they have a larger biomass per surface area. Halibut as small as five grams can be transported (although fish this small would likely be transported in bags with oxygen and kept cold), but tank densities of fish this size would be very low to keep less than four layers of fish. Typical transport densities, depending on length of transport, temperature, and size of fish, range between 40 and 100 kg/m^3 (Brown, 2002). Optimal densities for transporting halibut range from 45 kg/m^3 to 80 kg/m^3 (Brian Blanchard, Scotian Halibut Ltd., Clark's Harbour, Nova Scotia, B0W 1P0, *pers. comm.*). Ensuring optimal water quality parameters such as aeration, oxygenation and reducing pH to lower ammonia toxicity allows for higher transport densities (Grottum *et al.*, 1997). For water quality purposes, buffers and defoam products should be used. Buffers, such as soda ash are used to keep the pH of the water buffered. It is desirable to maintain pH levels between 7.0 and 7.6. Ammonia levels may become harmful if the pH reaches 8.0. Defoam products such as Defoam FG-10™ (Syndel Laboratories Ltd.) may be added to transport tanks to stop foam from forming on the water surface.

The bottom of a salmon smolt tank is slightly angled to allow for easy removal of wastes, water and fish at the site. However, steep angles in the bottom of the tank should be avoided so that halibut do not slide to one end during transport, pile up and suffocate. Layering the fish using shelving or mesh trays may prevent flatfish from aggregating in larger transport containers (Brown, 2002). The transport tanks use an internal aeration system with individual air lifts that blow air into the tank to keep water moving and to reduce super saturation of oxygen and nitrogen. Oxygen stones are placed on the bottom of the tank, covered by shields to minimize direct contact of fish with the stone. A false bottom in the transport tank could potentially improve transport by allowing water and oxygen to percolate up through the bottom and circulate in the tank more effectively, ensuring the oxygen levels stay high in the bottom of the tank without supersaturating the water on the surface.

Dissolved oxygen levels should be checked every 90 minutes during transport. Oxygen should be checked at one foot from the surface as well as at the bottom of the tank. Often the upper portion of water will have higher percent oxygen than the bottom where the fish have accumulated. In a high density tank an oxygen reading of 160 to 180% at the surface will generally mean 100-120% oxygen at the bottom (Brian Blanchard, Scotian Halibut Ltd., Clark's Harbour, Nova Scotia, B0W 1P0, *pers. comm.*). The amount of oxygen required for transport depends on temperature and density. If long stops or delays are anticipated, more oxygen in the tank is required. Ensure sufficient pressurized liquid oxygen is available for transport and extra

for emergencies. The action of a moving vehicle sloshes water and aids mixing of oxygen but improvements are needed in the oxygen distribution system to ensure more even oxygen distribution throughout the transport tank.

Once the transport truck reaches the farm, in the experiences of this study, a sluice has been used to pump fish from the transport truck into the cage. The sluice size was 10 inches in diameter, narrowing into a 6 inch pipe that carried fish to the cage. The size of sluice put a maximum size restriction for transport of approximately 450 g. For this reason, it was found that fish larger than 300 g do not fit well through the sluice. Some eye damage occurred when larger fish were sent out through the sluice. In a previous study it had been found that mechanical damage, while loading flounder into transport tanks and unloading into sea cages, was unavoidable (Min, 1994). For these reasons, it is recommended that larger fish be manually dipped out of the smolt tank into the cage. Canadian Halibut Inc. saw lower mortalities and greater survivability in fish that were hand dipped into cages. Hand dipping can become labour intensive if large numbers of fish need to be transferred. New technologies such as tanks with a false bottom that could be raised to pour the fish over the lip of the tank into an open faced sluice to be sent into the cage could speed up the transport process and reduce stress and or physical damage to the fish.

Fish may be fed the same day as transfer to sea-cages. However, depending on temperature, several days may be required before fish will resume eating normally. The expected mortality from transport should be less than 3% (Brian Blanchard, Scotian Halibut Ltd., Clark's Harbour, Nova Scotia, B0W 1P0, *pers. comm.*). The standard time for a hatchery to be responsible for transport mortalities is about one month. ***This time frame and compensation should be discussed and arranged when the contract is signed.***

3.4.1 Improvements and Necessary Research – Alternate Transport

Smolt tanks are designed for salmon smolt transport, and while they are adequate for halibut transport, some alterations could be made to customize the tank for flatfish transport. Some of these include a false bottom which could lift and pour fish out of the tank into the cage, a larger surface area for fish to lie on, and sectioned off spaces within the tank to prevent fish from piling on top of each other and suffocating. To speed up hand dipping, which appears to be less abrasive on flatfish, a system similar to that used during harvesting could be used with a boom system to raise a large net to lift fish from the transport tank to the cage.

Alternative methods for transporting within smolt tanks, including the use of coated wire cages (18cm x 61cm x 91cm, with 3.3cm2 mesh, or something similar) to increase surface area and prevent fish from lying on top of each other, are currently being assessed (Peter Sykes, Atlantic Veterinary College, UPEI, Charlottetown, PEI, *pers. comm.*). The cage size needs to be optimized for specific transport tanks to allow easy installation through the tank opening and best layout within the tank. This method of transport was recommended by Brown (2002) to aid in the avoidance of oxygen 'dead spots' in transport tanks.

It may also be possible to transport fish by boat depending on the location of the site with respect to the supplying hatchery. However, again, the farmer must weigh the risks and benefits regarding this means of transport.

4 HUSBANDRY PRACTICES

4.1 NUTRITIONAL SOPS

4.1.1 Nutrition

Feed represents the single largest operational cost of fish farming. Maximizing the efficiency at which halibut use the nutrients in their feed will help reduce these costs. For a detailed review of current and past research on halibut nutrition see Grisdale-Helland and Helland (2002).

Halibut are very efficient at utilizing protein, and may have low protein turnover rates (Martins *et al.*, 2007). The optimal dietary protein level for Atlantic halibut depends on body size (Grisdale-Helland and Helland, 2002; Hatlen *et al.*, 2005). Juvenile halibut (approximately 5-180 grams) have been found to benefit in growth from a dietary protein level of 56% or higher, whereas larger halibut (800 grams) experienced no benefit from protein levels above 41% (Grisdale-Helland and Helland, 2002). Hatlen *et al.* (2005) also found no effect of diet and protein on growth or feed efficiency in larger halibut.

The major protein source used in aquaculture feeds is fish-meal. Some alternative protein sources to fish-meal may include soybean-protein concentrate supplemented with methionine or wheat gluten supplemented with lysine (Grisdale-Helland and Helland, 2002).

It appears that halibut juveniles have a very low tolerance for dietary carbohydrate levels (Hamre *et al.*, 2003; Aksnes *et al.*, 1996). Smaller fish were found to benefit in terms of growth and feed efficiency at low carbohydrate levels of between 0-5% (Hamre *et al.*, 2003).

Halibut can tolerate a range of lipid levels, with 10-20% dietary lipid considered a safe level (Hamre *et al.*, 2003). The lipid component accounts for as much as 25% of the cost of feed. Unlike salmonids, halibut growth rates are not dependent on lipid content in feed. Halibut fed higher levels of dietary lipid (14% to 25%) did not experience any beneficial effects on growth and overall performance (Martins *et al.*, 2007). Thus, reducing dietary lipid levels could reduce costs for the grower without affecting growth. Certain levels of lipid are required in larger pellet sizes in order to bind the pellet together.

Feed companies are making continuous improvements to diets for all growth stages of Atlantic halibut as scientific results on nutritional requirements become available and the halibut farming industry expands enough to make feed optimization and production efforts economically viable for feed companies.

4.1.2 Feeding Techniques

The differences in feeding behaviour of halibut require some changes in feeding regimes compared to salmon feeding. Feeding takes longer in flatfish, particularly halibut, because they take longer to reach satiation (Brown, 2002). They also feed more slowly and continuously. Automated feeders that provide a small amount of food over longer periods of time are therefore more appropriate for halibut farming. A small amount of feed should be left on bottom as halibut

will pick up pellets off the bottom for a short period of time during feeding. Blind and smaller fish may especially rely somewhat more on bottom feeding as they are unable to compete with larger fish up in the water column. It is highly recommended that feed cameras be used during feeding to ensure fish are eating, feed is not being wasted and not too much food is falling to the bottom.

Halibut can become aggressive during feeding, especially at the beginning of hand feeding sessions (Greaves and Tuene, 2001). This can be avoided by combining hand feeding with automatic feeders at the start of the feeding session when fish are most hungry (Greaves and Tuene, 2001). Once fish are initially satiated, feed can be distributed more slowly.

The critical issue for farmers when feeding Atlantic halibut is that their feeding behaviour and seasonal feeding cycles do not emulate those of Atlantic salmon and new feeding protocols must be adopted for this species.

4.2 MORTALITY DIVES

Another unique husbandry challenge is mortality dives. During weekly mortality dives divers must separate the dead fish from the live fish lying on the bottom of the cage, which may be a time consuming process and quite expensive. Mortality dives can also be more time consuming since divers may be required to bring up any excess feed or waste from the bottom, especially in cages that are overfed and have a small mesh size that doesn't allow feed to fall through. For this reason it is highly recommended that feed cameras are used and proper feeding protocols for this species are followed (eg. slow feeding). In some cases site workers can use the amount of weekly excess feed being brought up by divers to determine whether to increase or decrease the amount of feed being fed, but this should not replace the need for cameras and proper feeding techniques.

4.3 SAMPLING, GRADING AND HARVEST

4.3.1 The Use of Seines

The benthic life style of Atlantic halibut poses challenges for routine handling practices such as seining, harvesting, and grading that are required in commercial operations. Some problems have been experienced with seining halibut as they easily become overcrowded when the surface area suitable for settlement is reduced, causing aggregations of fish that can quickly create lethal dead spots (Brown, 2002). When seining halibut it is helpful to have divers on-hand to monitor the fish in the seine to ensure adequate space and to prevent fish layering and suffocation. Tying the buoys of the seine to the opposite side of the cage increases the surface area of the bottom of the seine and helps prevent fish from crowding into one area of the net.

4.3.2 Sampling Recovery

Following sampling or anaesthesia it is recommended that halibut be provided with a recovery bath or smaller recovery cage. This way they can be monitored and prodded to move to increase water circulation over the gills. Since halibut lie on the bottom, fish weakened from anaesthesia

may be covered by unanaesthetized fish and suffocate if they have not recovered before they are returned to the cage.

4.3.3 Grading

Halibut growth especially in un-graded populations can be extremely variable. There are both genetic and sex related differences in growth of halibut. During harvest it is difficult to find a market for the varying sizes of fish. Larger fish can be dipped out during harvest times but this is not practical at a large scale. Improved broodstock selection, development of all female populations, and grading if necessary could aid in creating a more homogenous population in the cage for easier harvest.

4.4 NET CLEANING

Flat bottomed cages are necessary for providing adequate surface on which halibut can settle. However, changing nets when they become fowled is not as straightforward as with salmon nets because of the flat bottomed cage design. Ideally the nets could be replaced in the water and the dirty nets sent away to be cleaned and repaired. This process is labour intensive because of the fish net being tied to the ring. Another option, yet slightly less ideal, is to have divers use underwater pressure sprayers to spray the nets while they remain in the water. Pressure spraying nets is the most common practice being used today to clean predator and fish nets in halibut cages; however this process can be time consuming as well as stressful on the fish having divers in one cage for several days at a time. Prior to having divers pressure spray nets, the farmer should investigate the regulations put into practice by the provincial Department of Environment, as some sites are not allowed to use this protocol due to previous environmental assessment results. Better practices for standard operations such as net cleaning will be developed as the halibut industry becomes better established.

4.5 SHADING

Halibut, especially juveniles, are highly susceptible to sunburn when exposed to high levels of UV light (Bricknell *et al.*, 1996). Sunburn is frequently accompanied by fat cell necrosis in the fin areas that may be related to degradation of photolabile lipids. The absence of protective scales in turbot and sole make them more susceptible to sunburn (McFazden *et al.*, 2000) and the same may be thought for other flatfish species such as halibut. Juveniles and malpigmented fish appear to be especially susceptible to sunburn and fat cell necrosis, however, adult fish are still susceptible. It has also been found, in the case of other flatfish species (*eg.* plaice (Bullock, 1985)) that the fish became more susceptible to sunburn when infected by an ectoparasite. For this reason, the shading of halibut in cage culture is important as there is the possibility that the fish are susceptible to sunburn under a number of conditions, although nutrition (lowering dietary lipid) has been found to play a role in limiting effects caused by UV penetration (Bricknell *et al.*, 1996). Shade cloths covering the cage may be used to limit the exposure of halibut to sunlight in the summer months (See Figure 1). Shade nets that limit greater than eighty percent of the UV light from penetrating are recommended (Brown, 2002). The practice of using shade cloths throughout the halibut cage-culture industry seems to be sporadic. For example Scotland farms, at a latitude of 55° do not routinely use shading, while some sites in Norway (at a higher latitude

of 60°) use shading. It is recommended that sites in Atlantic Canada, at latitude of 45° which would experience a higher UV index, use shading as a preventative measure.

Shade cloths may be draped over the interior ring (bird net ring) that supports the bird predator net. In the case of the farm at Lime Kiln Bay, the shade cloths needed to be suspended twice as high as bird net rings used in salmon farming for easier feeding access. If the farm utilizes hand-feeding as the primary feeding method, it is recommended that taller bird net rings be used. Archway openings on one or more sides of the cage from which the sunshades are suspended makes feeding easier, however, improvements are still needed. An automated feeding system would alleviate any problems of distributing feed appropriately without interference from shade cloths.

Documentation on the effects of UV light on halibut in cages varies. In Lime Kiln Bay, 2-3 kg halibut were exposed to sunlight for an entire summer and did not experience fat cell necrosis or other sun related problems. This may suggest that sunshades are not necessary once halibut reach a certain size. Other experience shows that larger halibut are still affected when exposed to sunlight, therefore, we recommend the use of shade cloths especially during summer months.

4.6 STOCKING DENSITIES

Currently, the general consensus is that halibut can be stocked at densities as high as 30 – 50 kg/m^2 although Brown, 2002 suggested stocking densities up to 80 kg/m^2. If densities are too high, both fish behaviour and growth can be impacted. Halibut have been found to increase their swimming activity and reduce their feeding activity at higher densities, thus resulting in reduced overall growth (Kristiensen *et al.*, 2004). At high densities competition and aggression may become a problem, particularly for smaller juveniles. Aggressive behaviour can lead to eye picking (Greaves and Tuene, 2001, Williams and Branckner, 2004; 2006), resulting in eye damage and blindness compromising optimal feeding activity.

It is thought that aggression may be reduced by regular size grading of fish. Grading reduces size variation, which, if left unchecked, may result in cannibalism and increased aggression (Brown, 2002). Sunde *et al.*, 1998 found that feeding fish frequently and in excess seemed to reduce aggressive behaviours, and possibly discouraged hierarchal interactions. In this study growth may not have been affected in ungraded populations because the fish did not have to compete for feed. In less optimal growing conditions more aggressive interactions may occur causing eye picking, nipping and fewer opportunities for smaller fish to access feed.

Conversely, other studies have also shown that size grading of halibut (Stefansson *et al.*, 2000) and turbot (Sunde *et al.*, 1998) did not improve overall growth. Growth in graded populations may be suppressed due to suppressed behavioural interactions associated with establishing social hierarchies (Stefansson *et al.*, 2000). Imsland *et al.*, 2009 concluded that juvenile halibut should not be too intensively size graded (). Although size grading may save the farmer time and money during harvest, as cages have a more uniform size distribution, grading can be costly from an economic and a health standpoint. Handling fish can cause ocular lesions (Williams and Brancker, 2004; 2006), and may also induce stress and disease outbreaks (Sunde *et al.*, 1998).

5 ECONOMICS AND MARKETING

Once juveniles are put into the sea-cage, the grow-out period generally takes 2 to 2.5 years to reach a market size of 3 to 5 kg (Bromage *et al.*, 2000). However, again, this depends on the size of juveniles at transfer, as previously discussed. Figure 2 shows a hypothetical growth projection model for halibut that estimates a grow-out period of 3.5 years. Costs associated with rearing will include capital equipment, the initial cost of juveniles, feed, salaries and benefits, insurance, transport, depreciation, health services, diving services, site fees, office, operation and maintenance costs, processing and interest payments. It is recommended that the farmer consider these collective costs in planning stages.

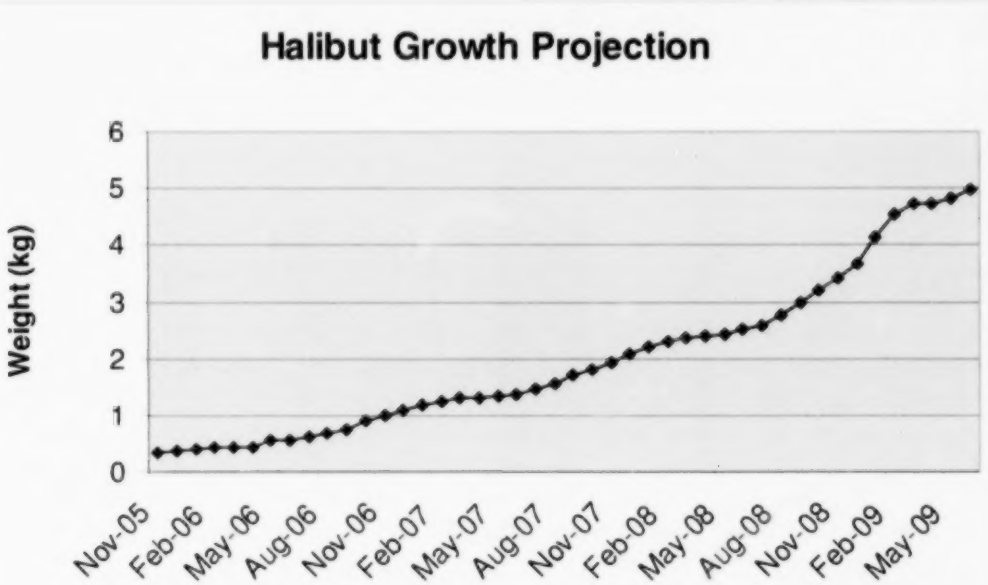

Figure 2 – Growth projection (as made available by Canadian Halibut Inc.) for halibut put into a cage site at an average weight of 300 grams. This projection estimates that halibut will reach market size in 3 years of grow-out.

5.1 COST OF JUVENILES

Currently, purchasing halibut juveniles is the most expensive sole investment in developing a farm site in Atlantic Canada. The production of juveniles in Canada today is still relatively low compared to those in Iceland and Europe, primarily due to the limited number of buyers. The cost of juveniles in Canada remains high in order for hatcheries to afford the high capital costs of the hatchery and nursery stages. Prices will come down once hatcheries have enough buyers to allow full-scale juvenile production. Until then 300-500 g juveniles cost approximately $13-15 Canadian each. To purchase 50 g halibut, which have yet to experience the nursery stage, the cost is reduced to $10 per fish. The farmer must weigh the risks of putting smaller fish into the cages compared to the savings in juvenile costs. Another consideration is the additional cost per

fish to rear 50 g halibut to the 300 – 500 g stage. Juvenile costs will be reduced once consistent full-scale production is realized.

In the future, the halibut industry may have to consider juvenile purchasing agreements with the hatcheries. The price of juveniles could be standardized on a gradient according to health, size, history, etc. Some of the unique health issues associated with halibut such as improper eye migration and malpigmentation should be considered in the price of juveniles, especially if optimal growth rates in sea-cages are found to be compromised by the health issues encountered at the hatchery stage. With the price of juveniles so high, the farmer should ensure the health of the juveniles prior to purchase.

Early maturation and slow growth of male halibut is a critical impediment to the profitability margins of halibut culture. Not only do male halibut grow more slowly, muscle fiber density is significantly higher in female halibut and flesh quality is more consistent since females do not mature prior to harvesting (Björnsson, 1995; Hagen *et al.*, 2006; Roth *et al.*, 2007). All-female juvenile Atlantic halibut are now being produced in Canada and the ability to purchase all-female stocks from hatcheries/nurseries will provide growers with superior growth performance compared to mixed sex stocks.

5.2 MARKET

Atlantic halibut exists within a niche market, being traditionally a high priced fish and mainly being bought by high-end buyers, making the species especially suitable for culture. Atlantic halibut would likely compete for markets of other white-fleshed fishes such as cod and haddock. However, being a cultivated product, farmed Atlantic halibut should obtain a premium price as flesh quality and freshness should be above that of wild- caught similar species. It has been recommended in a recent marketing study (Beibei *et al.*, 2008) that because production in Atlantic Canada has been small, thus far, that farmers should take advantage of markets close by to cut down on the expensive costs of shipping fresh products, over long distances. Such markets exist in the eastern sea-board cities of the United States, such as Boston and New York. There are no certification requirements for fish products being sold and exported to the United States. However, the fish must be processed in a federally registered establishment to appear on the List of Canadian Establishments Approved for Export to the United States. Buyers from the United States will refer to this list prior to purchasing product from Canadian markets http://www.inspection.gc.ca/english/fssa/fispoi/export/usexporte.shtml. A dependable supply of high quality fresh product, consistently priced for up-scale local restaurants, is the ideal market to target now while production is building to more sustainable levels to satisfy an expanded market (Beibei *et al.*, 2008).

6 CONCLUSIONS

Although the culturing of Atlantic halibut in Atlantic Canada, specifically the Bay of Fundy region, has only had a small scale existence thus far, it shows excellent potential for expansion to become a major player in Canada's aquaculture industry. This manual has outlined some of the

necessary considerations upon initiating a halibut sea-cage commercial venture. However, with the growth and expansion of a sea-cage site, technologies used for husbandry and feeding purposes should become more advanced with industry growth, and thereby become more efficient. It is hoped that this manual will aid the industry by disseminating preliminary information specific to cage culture of Atlantic halibut in the Bay of Fundy and encourage expansion of the industry.

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APPENDIX A: *Pictures*

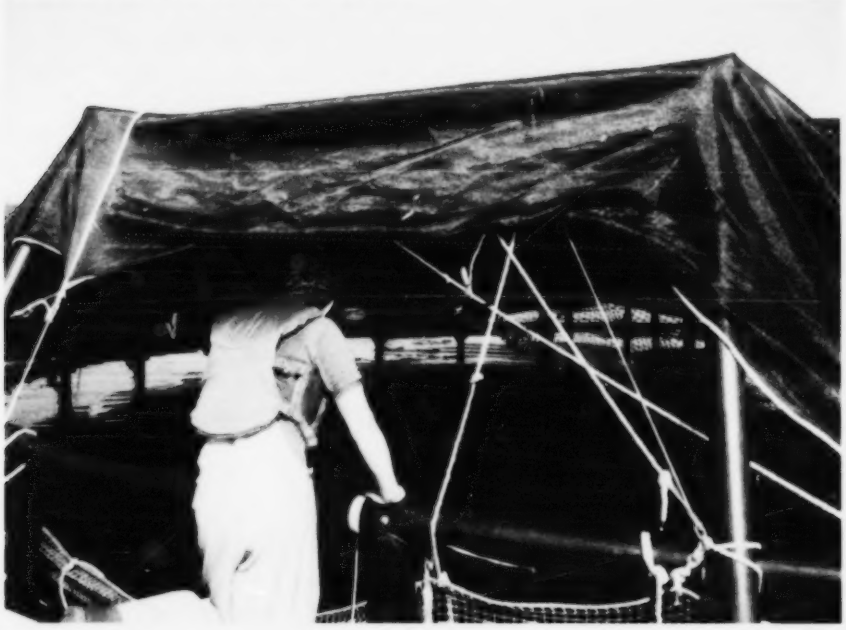

Figure 1 – Shade cloth covering halibut cage at Canadian Halibut, Lime Kiln, NB. Archway provides area for feeding. (Photo credit: Erica Stuart, DFO St. Andrews Biological Station)

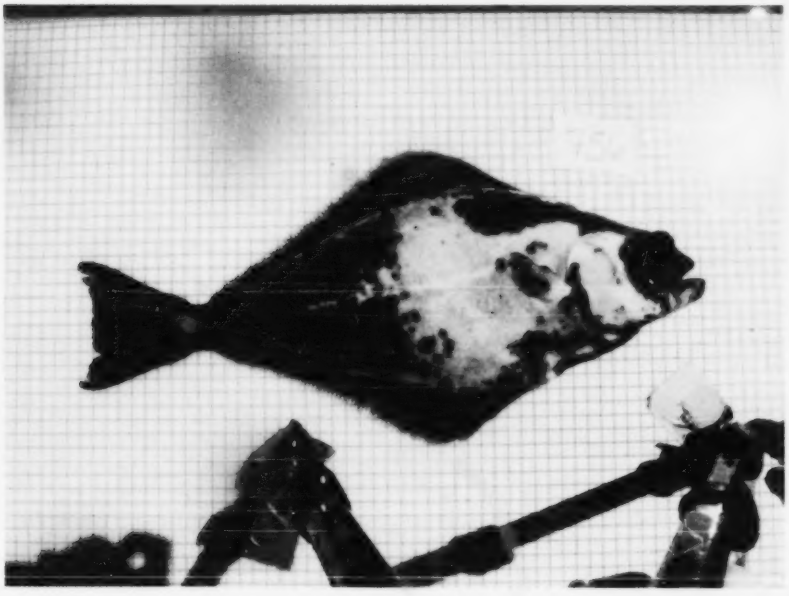

Figure 2 – Atlantic halibut showing malpigmentation. July 2008. (Photo credit: Joanne Power, UNBF-DFO)

Figure 3 – Transfer pipe from smolt truck to halibut cage, Lime Kiln Bay July 2008. (Photo credit: Tim Burnley, Centre for Aquatic Health Sciences)